INSTRUMENTS FOR THE ASTROPHYSICAL INVESTIGATIONS OF MARS

V. I. Moroz, L. V. Ksanformalit, et al.

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16. Abstract Brief descriptions are presented of a number of devices installed on an artifical satellite of Mars. These include a narrow band infrared photometer for determination of the H_2O content in the atmosphere of Mars, an infrared radiometer, a photometer for measurement of the distribution of brightness over the planet, an infrared photometer for the CO_2 absorption band, a photometer-polarimeter, an infrared spectrophotometer, a two-channel ultraviolet photometer, a plasma particle spectrometer, devices for study of the solar wind and the plasma near the planet, a magnetometer, a gamma spectrometer, a radiometer and an ultraviolet photometer. Apparatus installed on the descent module are also discussed, including a temperature and pressure meter and a mass spectrometer.

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INSTRUMENTS FOR THE ASTROPHYSICAL
INVESTIGATIONS OF MARS

V. I. Moroz, L. V. Ksanformaliti, et al.

Narrow Band Infrared Photometer for Determination of the H_2O content in the Atmosphere of Mars

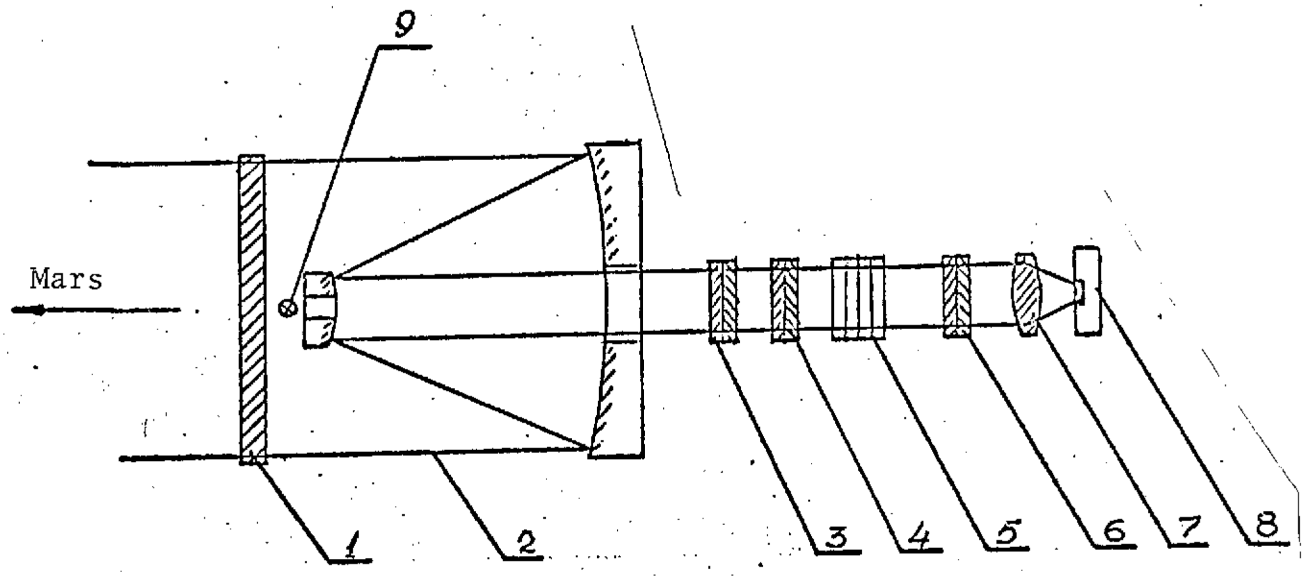
Scientific Leader Doctor of Physical and Mathematical Sciences, Professor V. I. Moroz

This device is designed to measure the content of water vapor in the atmosphere of the planet on the basis of the absorption at the center of the band at 1.38 μ. The H_2O band with $\lambda = 1.38$ μ is formed in the spectrum of reflected solar radiation and its equivalent width is practically independent of the vertical distribution of temperature in the atmosphere of the planet. /3*

Since the expected equivalent width of even the strongest lines in the center of the 1.38 μ band in the spectrum of Mars is slight, the modulation method is used for its measurement. An interference-polarization filter, consisting of a plate of Iceland spar (doubly refracting crystal 5) and two poloroids (4, 6), and interference filter (3) separate three lines at the center of the band: 13788, 13807 and 13827 A. When the second poloroid (6) is rotated, the transmission maxima of the interference-polarization filter are alternately interchanged with the minima and the intensity at the output of the device is modulated if absorption lines are present. The amplitude of the modulated component of the signal depends on the energy absorbed in the lines. The optical plan of the photometer is shown in the figure. A cassegrain lens is used, diameter 80 mm, aperture ratio 1:20, angular field of view 0.005 radian (6 km at a range of 1500 km); the radiation receptor is a lead sulfide photoresistor.

*Numbers in the margin indicate pagination in the foreign text.

Nonmoving poloroid (4) is oriented in relation to the main axis of the doubly refracting crystal (5) at an angle not exactly equal to 45°. As a result, a second modulated component appears, the amplitude of which is determined primarily by the continuous /4 spectrum. It is significant that it is shifted in phase by 90° in relationship to the first component and the corresponding electrical signals are easily separated by phase detectors. Two voltages are measured at the output of the device, the ratio of which depends on the equivalent width of the absorption lines. The operation of the device is tested in flight by test lamp (9), which is turned on for several minutes before the optical axis intersects the limb of the planet and after the terminator is passed.



Infrared Photometer for Determination of
H_2O Content

Infrared Radiometer

Scientific Leader Candidate of Physical and Mathematical Sciences L. V. Ksanfomaliti

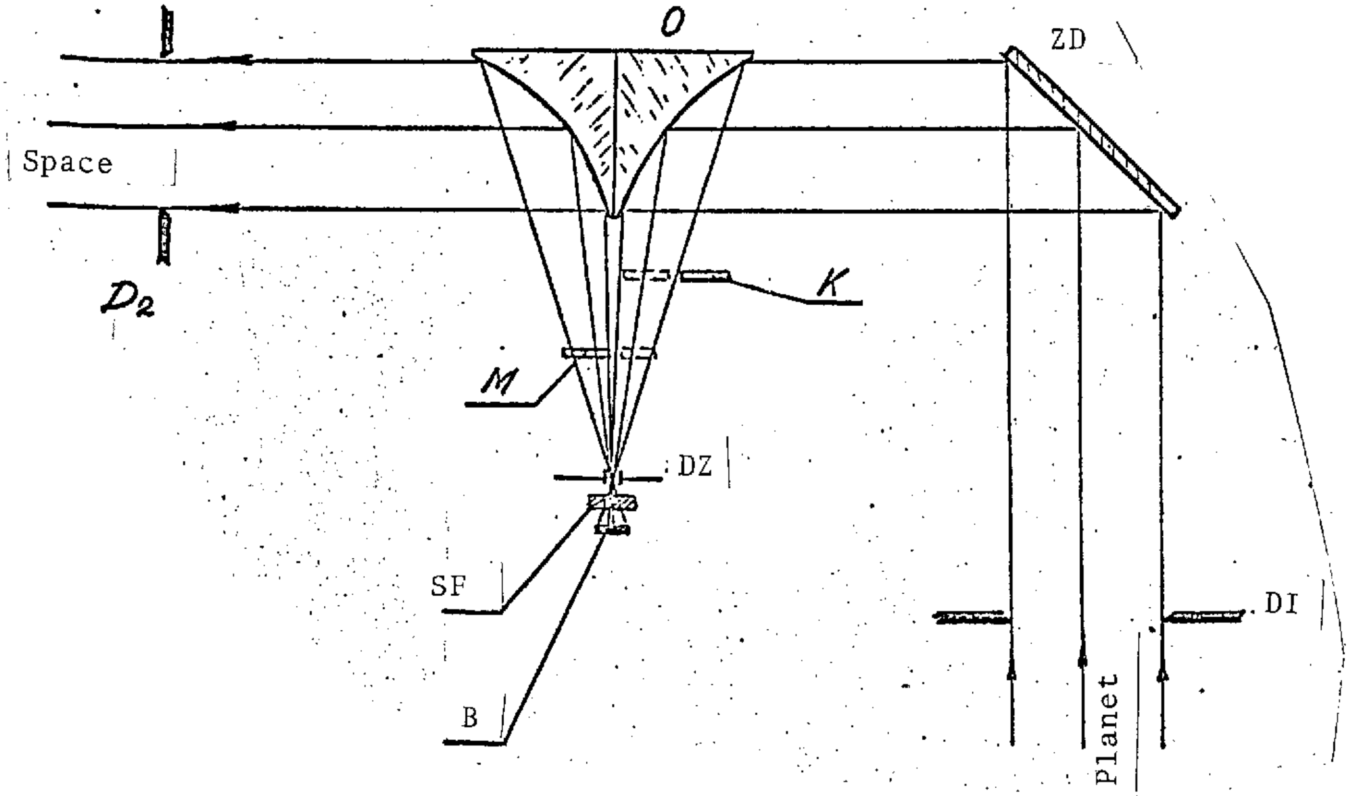
The radiometer is designed to measure the brightness temperature of a source in the range of 8 to 26 μ with rejection of the carbon dioxide band at 15 μ. The brightness temperature of the surface of Mars in this range is rather close to the thermodynamic temperature of the surface. /6

The radiometer is constructed according to a dual-beam comparison modulation plan. The nonselective receptor is a metallic bolometer. The radiation from the planet passes through the diaphragm (DI) and through diagonal mirror (ZD) to the lens (O), consisting of two parabolic mirrors glued together. The radiation is collected by the lens, focussed on the field diaphragm (DZ), which separates an angle of about 1°, corresponding at the pericenter to a section of about 30 km on the surface. In the plane of the diaphragm is also a light filter (SF), transmitting radiation in the 8-13 and 17-26 μ ranges to the bolometer receptor.

Before the field diaphragm is a vibration modulator (M), which periodically interrupts the flux from the mirrors at a frequency of 10 Hz, so that the bolometer records the difference in the fluxes received from the "planet" and "space" channels.

The variable component is separated by a phase-sensing amplifier. The amplifier has low noise (corresponding to an input level of less than 1 nv) and high gain (about $50 \cdot 10^6$). For absolute calibration, plate (K), the temperature of which is measured, is periodically inserted into the "planet" channel.

The working range of brightness temperatures recorded by the radiometer is 120-310 K. The probable error in recording of radiation from a source with T_V = 250 K is not over 2°. The sighting direction is parallel to the axis of the FTU [Expansion unknown -- tr.].



INFRARED RADIOMETER

Photometer for Measurement of Distribution of Brightness Over the Planet

Scientific Leader Candidate of Physical and Mathematical Sciences L. V. Ksanfomaliti

A wide-band photometer, designed for measurement of the brightness of the surface and atmosphere of Mars, with a set of interference filters centered on the following wave lengths λ with band widths $\Delta\lambda_{0.5}$: /8

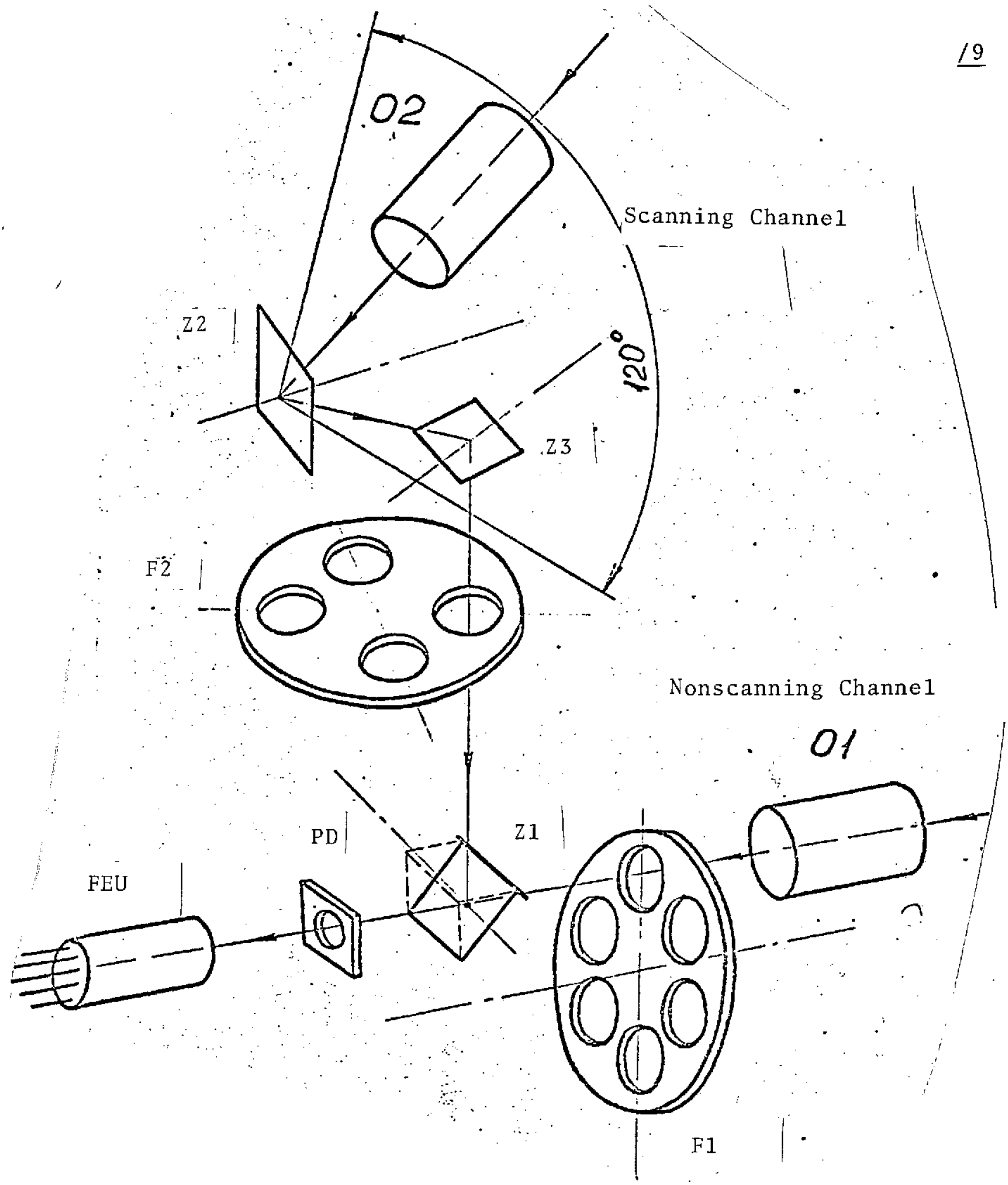
λ	$\Delta\lambda_{0.5}$
7030 A	100 A
5210 A	90 A
4910 A	90 A
4100 A	80 A
3700 A	300 A
3200 A	60 A

The field of vision provided by the lenses is 1°.

The photometer has two operating modes -- nonscanning and scanning. In the first case, the direction of sighting is parallel to the axis of the FTU. In the second case, scanning is in the plane of the orbit, making it possible to perform measurements along a track at various phase angles. The angle of view with scanning is 120°, scanning rate 6°/sec. Measurements are performed only in one filter λ = 7150 A ($\Delta\lambda$ = 300 A) with a sample of 180 sec. In the nonscanning mode, the filters (F) are changed each second.

The limits of brightnesses which can be recorded are $2.3\cdot10^{-2}-0.20\cdot10^{-4}$ w/cm$^2\cdot\mu\cdot$ster.

The lenses of the photometer (01 and 02) are quartz, diameter 20 mm, focal length 100 mm. The receptor is a photomultiplier (FEU) with a multiple-slit photocathode. The electronic system has a gain of 1. At these flux levels, noise in the photometer can be ignored.



Photometer for Measurement of the
Distribution of Brightness over the Planet

Infrared Photometer for CO_2 Absorption Band

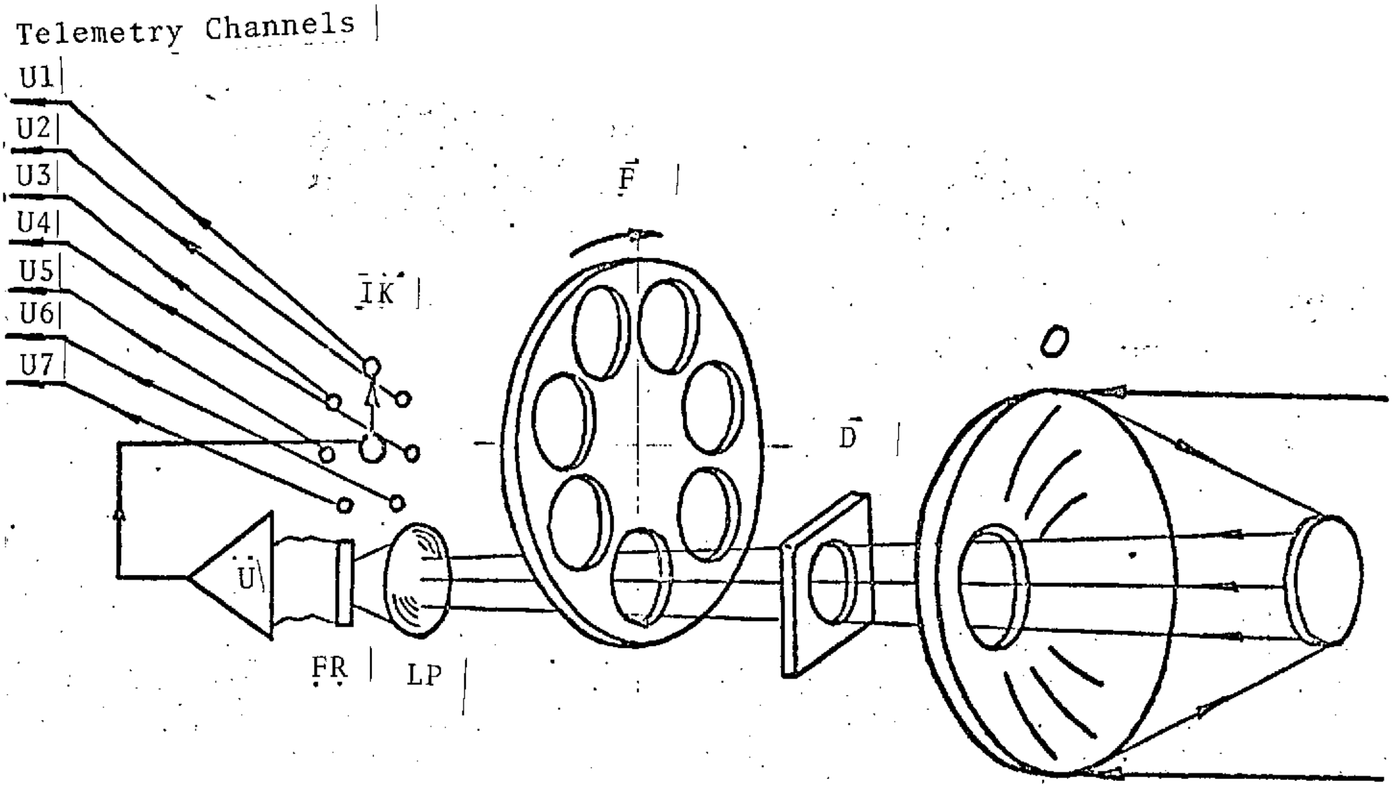
Scientific Leader Candidate of Physical and Mathematical Sciences L. V. Skanfomaliti

The purpose of this photometer is to produce information on the equivalent CO_2 absorption band width in the wave lengths 2.01, 2.03 and 2.06 μ, allowing the position of the surface reflecting the solar radiation relative to the reference level to be determined.

The reception pattern of the instrument is 0.5° in width, the diameter of the cassegrain lens (O) is 35 mm. Disc (F) carrying 7 filters with wave lengths of 1.919, 1.961, 2.273, 2.013, 2.043, 2.052, 2.271 μ rotates rapidly before field lens (LP).

The radiation passes through the field lens to receptor (FR), a PDS photoresistor. The signal is amplified by a broad band amplifier with AGC and sent to a 7-channel electronic switch (EK), which is synchronized with the filter disc. This causes information on each point on the surface to appear in each of the 7 parallel channels.

The limits of brightness recording are from $0.5 \cdot 10^{-4}$ to $5 \cdot 10^{-2}$ w/cm$^2 \cdot \mu \cdot$ster. The direction of sighting is parallel to the axis of the FTU.



IR Photometer

Photometer-Polarimeter

/12

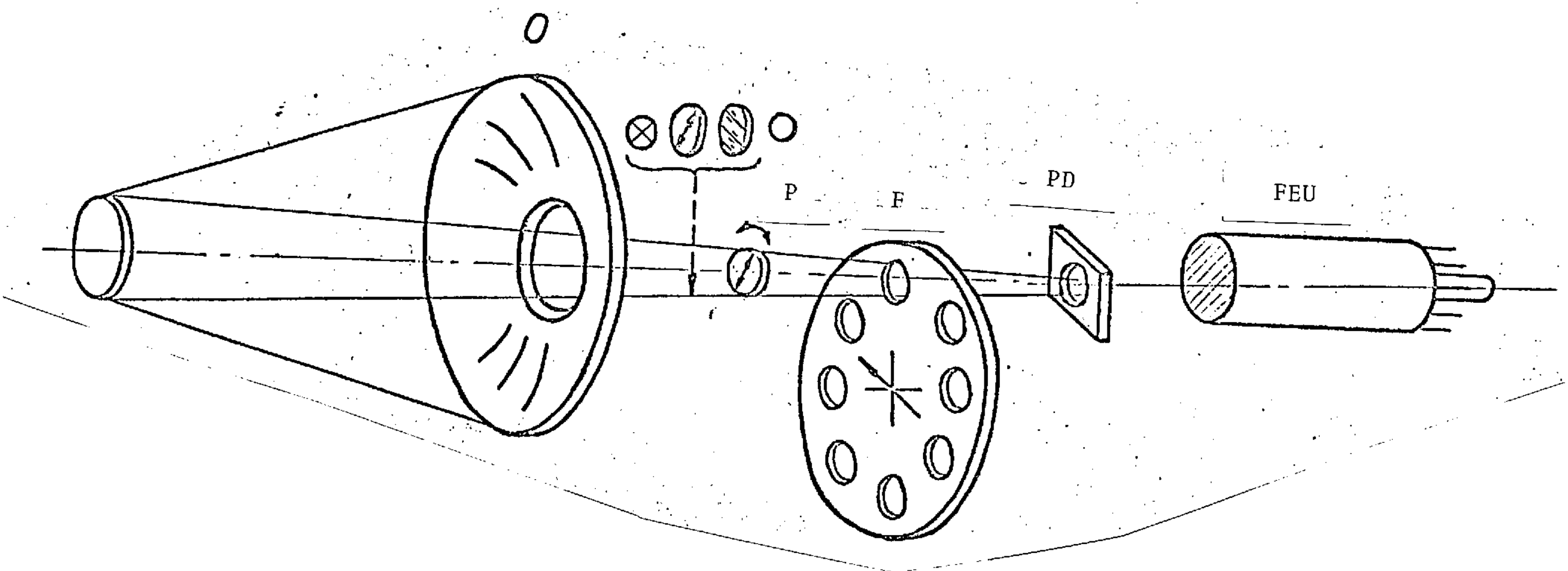
Scientific Leader Candidate of Physical and Mathematical Sciences L. V. Skanfomaliti

The polarimeter is designed to measure the degree of linear polarization of light approximately to 20% of the angle of the plane of polarization, determined in two projections P_x and P_y, as well as the brightness of the section of the surface or atmosphere. The spectral range of the device is from 3500 A to 7500 A. The rotating disc of filters (F) includes 9 interference filters centered at 3500 A, 4000 A, 4500 A, 5000 A, etc. to 7500 A, with band widths of 70-120 A. The range of recorded brightnesses is from $2 \cdot 10^{-5}$ to 10^{-2} w/cm$^2 \cdot \mu \cdot$ster. The interrogation cycle of all filters is 9 seconds.

The probable error of recording of polarizationof 1% is 0.26%.

The field of vision of the device is 0.5°, which corresponds to 15-17 km on the surface of the planet at the paracenter. The diameter of the cassegrain lens (O) is 60 mm. Light passes through the rotating analyzer (poloroid P), filter, field diagram (PD) and strikes the cathode of the photomultiplier (FEU). From the matching amplifier (gain factor 1), the signal si sent to a synchronous commutator, which separates it into x and y projections. The AGC system makes the output signals independent of the brightness of the object observed, while a voltage proportional to the logarithm of brightness is delivered to the output.

In order to product information on various parts of the phase curve of polarization, the spacecraft carries two photometer-polarimeters oriented at 30° relative to each other.



Photometer-Polarimeter

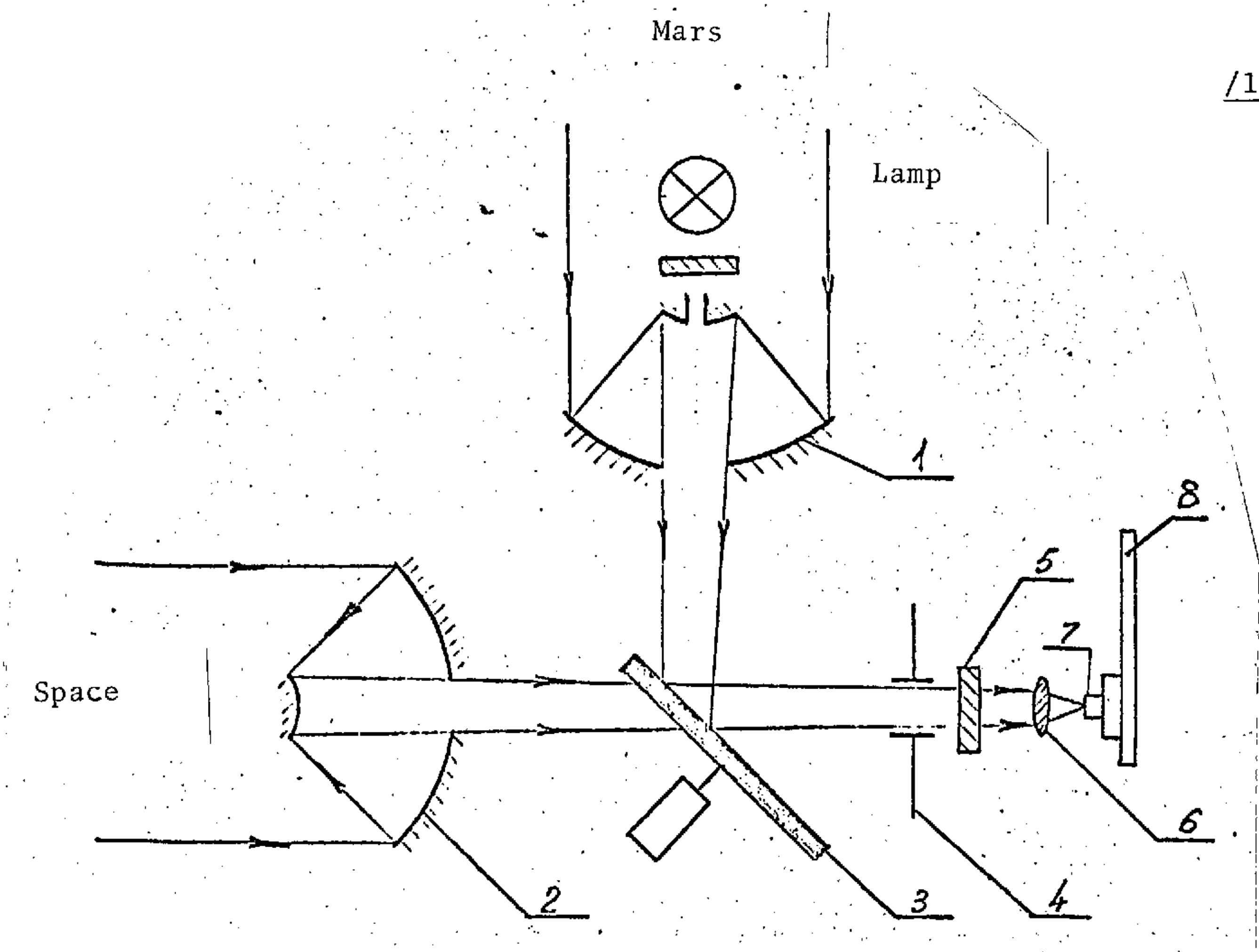
Infrared Spectrophotometer /14

Scientific Leader Doctor of Physical and Mathematical Sciences Professor V. I. Moroz

The information produced from this device allows altimetry of Mars, estimation of the surface temperature and a judgment of the composition of the surface rocks of the planet.

The device has 10 spectral channels (1.75, 2.00, 2.25, 2.55, 3.2, 3.5, 4.66, 5.1, 5.5 μ and an integral 1.5-5.5 μ brightness channel). The optical system is shown in the figure. The radiation from the planet passes through lens (1); lens (2) is directed to space. Where the beams intersect is mirror-type modulator (3). Beyond field diaphragm (4) is a cassette of interference filters (5). The radiation of the planet, separated by the interference filters, is collected by lens (6) and strikes PbSe receptor (7) which is cooled by radiator (8). The signal processing system includes a two-channel amplifier, a synchronous detector and a direct current amplifier.

/15

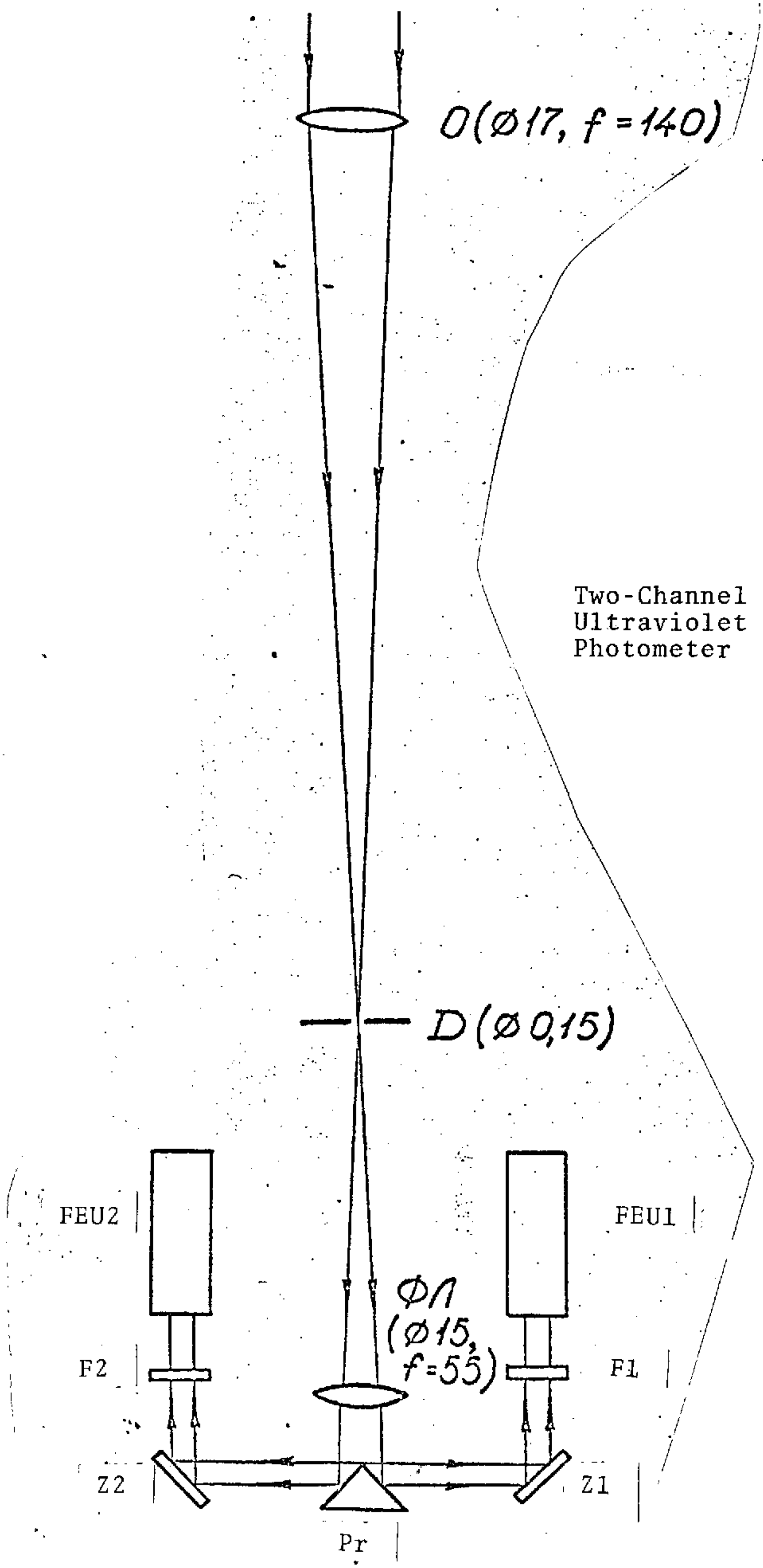


Infrared Spectrophotometer

Two-Channel Ultraviolet Photometer

Scientific Leader Candidate of Physical-Mathematical Sciences
V. A. Krasnopol'skiy

This device measures the radiation of the planet at wave lengths 2600 A and 2800 A. The small diameter of the field of vision, amounting to 5 minutes considering aberrations, allows us to produce a photometric profile on the limb of the planet. Due to the significant increase in the mass of the atmosphere here, it is possible to detect very low (greater than or approximately equal $3 \cdot 10^{-5}$ atm·cm^2) quantities of ozone. The information produced can also be used to study the characteristics of the aerosol layer, since we can expect significant aerosol absorption on the limb of the planet even when no dust storms are present. Measurements on the disc of the planet can be used to study the relief of the planet. The radiation passes through lens (O) and the diaphragm of the field of vision (D) to the flux separation device, consisting of a lens (FL) and a prism (Pr). In each channel is an interference filter (F1 and F2) for the corresponding wave length with a transmission band width of about 100-150 A and a photomultiplier (FEU1 and FEU2) with measurement system. The diaphragm is located at the focal point of the lens.



Two-Channel
Ultraviolet
Photometer

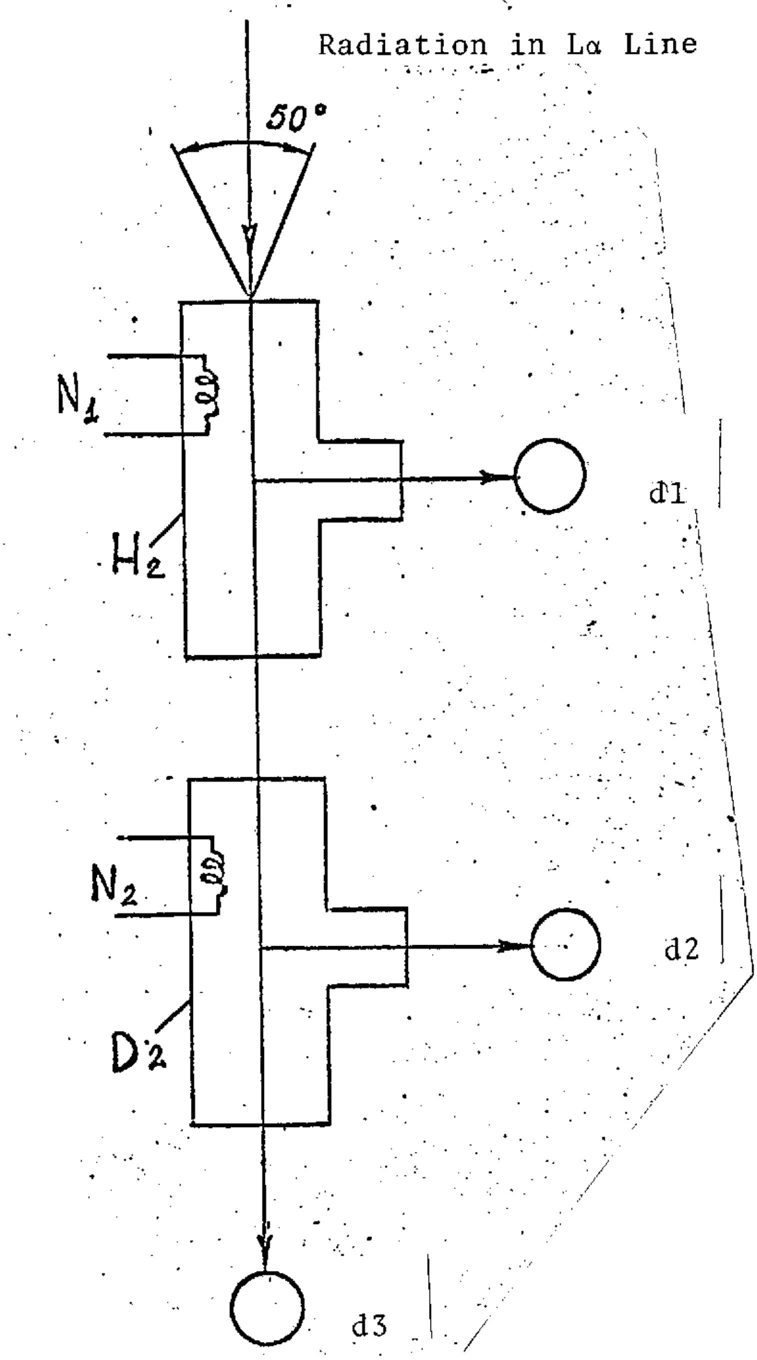
Ultraviolet Photometer /18

Scientific Leader Doctor of Physical and Mathematical Sciences V. G. Kurt

The ultraviolet photometer is designed to record radiation in the wave lengths of hydrogen and butyrium $L\alpha H\lambda = 1215.7$ A and $L\alpha D\lambda = 1215.4$ A.

In order to separate such close wave lengths, the device uses two resonant chambers filled with hydrogen and butyrium with three lithium fluoride windows. The heating filaments in the chambers cause the hydrogen and butyrium to dissociate, resulting in resonant scattering of the radiation in the $HL\alpha$ and $DL\alpha$ lines. Three narrow band photon Geiger counters sensitive in the 1050-1340 A wave length range are used as detectors. The counters are surrounded by plastic scintillators, the pulses from which are used in anticoincidence circuits to reduce the cosmic ray background level. Two detectors record radiation resonant scattered at an angle of 90°; one detector records the direct radiation. The field of vision of the device in the direct channel is 5°.

The window of the device is periodically covered to measure the charged particle background.



Ultraviolet Photometer

H_2, Chamber filled with molecular hydrogen

D_2, Chamber filled with molecular butyrium

d_1, d_2, d_3, Detectors in 1050-1340 A area

N_1, N_2, Chamber heating filaments

Radiometric Apparatus /20

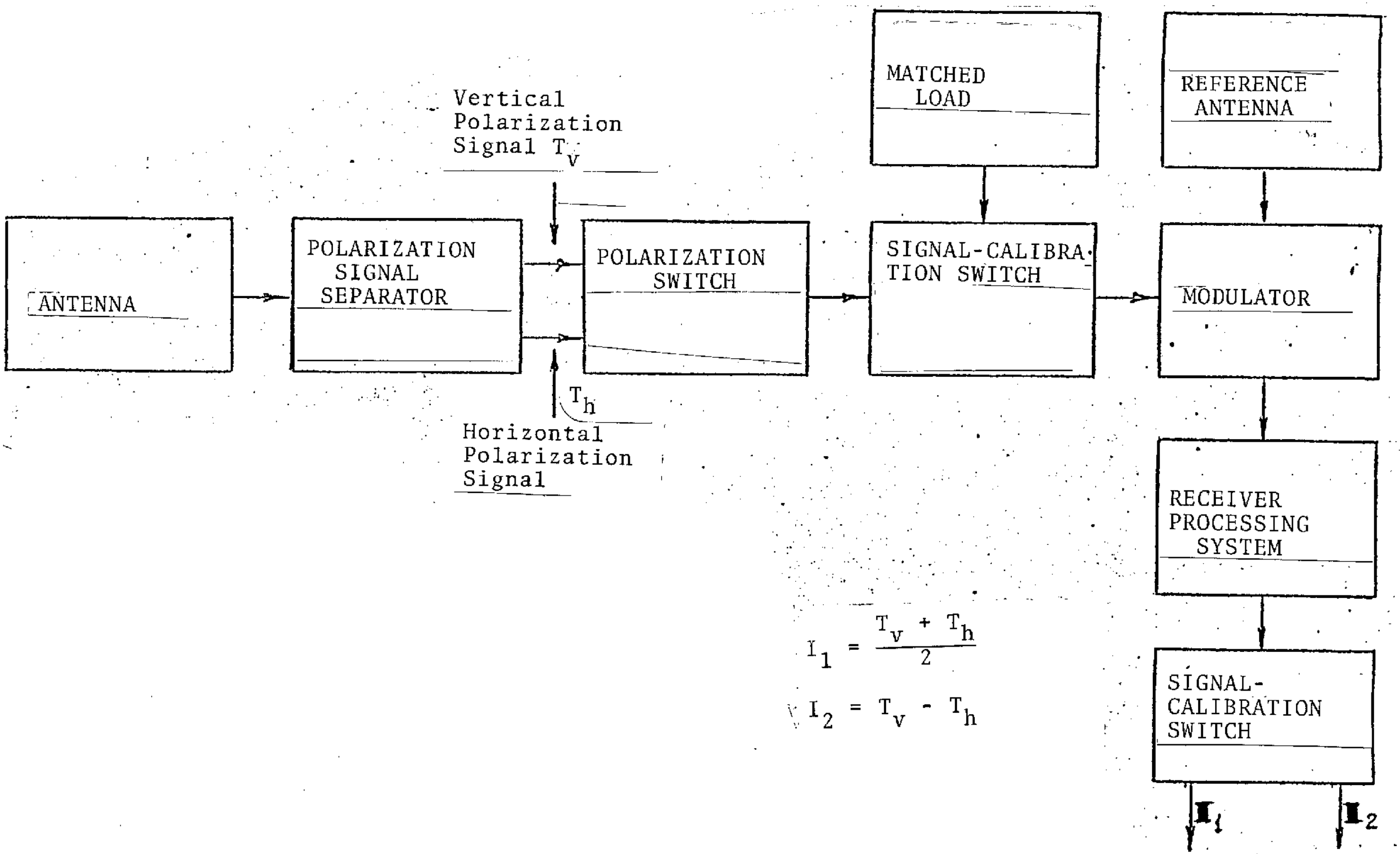
Scientific Leader: Candidate of Physical and Mathematical Sciences N. N. Krupenio

This apparatus consists of a modulation radiometer measuring the intensity and polarization of radio radiation from the surface layer of Mars at a wave length of 3.4 cm.

The radiometric apparatus receives radio radiation in two linear orthogonal polarizations through a parabolic antenna, the reception pattern of which is identical in both planes and in both polarizations. The width of the reception pattern at the half power level is ±2°. The level of the side lobes of the antenna is -30 db.

The signals of the radio radiation of space, received through a reference antenna ($T_k \simeq 3$ K) and the radio radiation of a matched wave guide load ($T_k \approx 300$ K; physical temperature measured by a thermosensor) are used as calibration signals in the radiometer. Signals proportional to the half sum and difference of the antenna temperatures are separated at the output of the radiometer (I_1 and I_2; see block diagram).

The data on radio brightness temperatures for the vertical and horizontal polarizations are used to determine the thermodynamic temperature of the surface layer to a depth of 0.5-2 meters and the effective dielectric permeability of this layer.



Block Diagram of Radiometric Apparatus

Plasma Particle Spectrometer /22

Scientific Leader Candidate of Physical and Mathematical Sciences O. L. Vaysberg

The plasma particle spectrometer is designed to measure the energy distribution of ions and electrons in the plasma flux, and also to search for fluxes of fast neutral atoms.

The device is made according to the modular principle and consists of 8 identical independent subspectrometer channels, each of which includes a cylindrical electrostatic analyzer with a channel electronic multiplier as a detector, and a recording circuit. A magnetic charged particle test filter is installed in the channel before the foil analyzing system in order to record neutral atoms. Five channels are designed for measurement of the energy distribution of ions in the 0.05-20 KeV energy range, two channels are designed to measure neutral atoms in the 0.3-4.3 KeV range, and one is designed to measure electrons in the 10-100 eV range.

All channels have identical energy and geometric characteristics: resolution $\Delta E/E = 5\%$, the range of measured flux densities is 10^5-10^9 particles/cm$^2\cdot$sec$\cdot$ster in a solid angle of $2\cdot 10^{-3}$ ster. The prinary axis of vision of the device coincides with the axis of the spacecraft.

Two channels out of 8 for measurement of ions and fast neutral atoms in the 0.3-3 KeV energy range are rotated relative to the axis of vision of the device by 45°.

The energy spectrum is made up of the partial subspectra, measured independently by each channel in the 8 energy intervals in each minute.

Depending on the operating mode, the full spectral distribution is measured each 2 minutes, once each 10 minutes or once each 20 minutes. The measured energy spectra are used to produce the following parameters of the plasma flux: velocity, temperature, relative concentration and temperature of alpha particles.

Instruments for Investigation of the Solar Wind and the Plasma Near the Planet /23

Scientific Leader Doctor of Technical Sciences K. I. Gringauz

This device is designed for measurement of the differential energy spectra of the ion component of the solar wind and the volt-ampere characteristics of the electron component.

The ion component was measured by means of a modulation trap as diagrammed in Figure 1. This same figure shows the potentials of the electrodes of the trap relative to its body.

The modulation traps were installed on the illuminated side of the spacecraft. The ion spectra were measured primarily with an angle between the perpendicular to the aperture of the trap and the direction to the sun of less than 1°.

Each energy spectrum was measured in 16 energy intervals as shown in Table 1.

TABLE 1

Interval Number	1	2	3	4	5	6	7	8
Width of Energy Interval, eV	0-40	40-70	70-103	103-200	200-332	332-500	500-700	700-930

9	10	11	12	13	14	15
930-1195	1195-1500	1500-1835	1835-2225	2225-2625	2600-3060	3060-3550

16
3550-4100

Measurement of one energy spectrum required 51 sec, the time interval between recording of neighboring spectra could be selected as 2 minutes, 10 minutes or 20 minutes.

Considering the characteristics of the trap, amplifier and telemetry system, the device allows ion fluxes in the range of 10^6-10^{10} ion/cm·sec to be measured in each energy interval.

The electron component of the plasma flux was measured by means of the trap diagrammed in Figure 2. The electron trap has four electrodes; the analysis gap is formed by two spherical grids (3-4), while the two flat grids (5), galvanically connected, serve as an electrostatic screen. The overall optical transparency of the system of grids of the trap is 0.6. Collector (6) is made in the form of a flat electrode with a "honeycomb" fitting. All electrodes of the trap, its internal surface and slats (2) (designed to reduce the number of electrons reflected from the walls of the trap) are covered with gold. /24

The nominal levels of decelerating (analysis) voltages are presented in Table 2.

TABLE 2

Step No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Decelerating Voltage (v)	0	2	4	7	10	14	18	23	29	35	50	75	100	150	200	300

The apparatus allowed electron fluxes of 10^7 cm^{-2} sec^{-1} ster^{-1}-$5 \cdot 10^{10}$ cm^{-2} sec^{-1} ster^{-1} to be measured.

The electron traps were installed on the shaded side of the spacecraft.

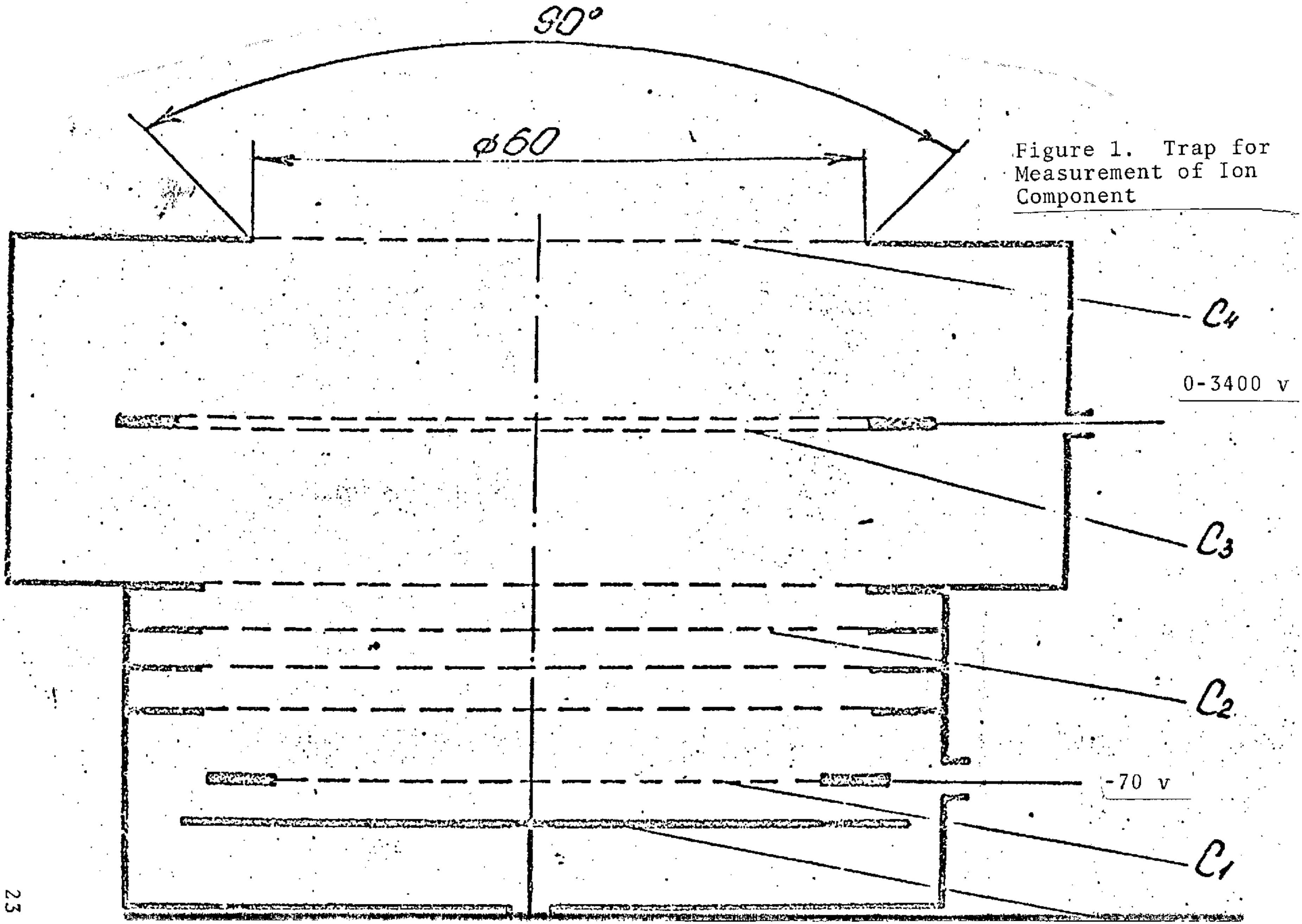


Figure 1. Trap for Measurement of Ion Component

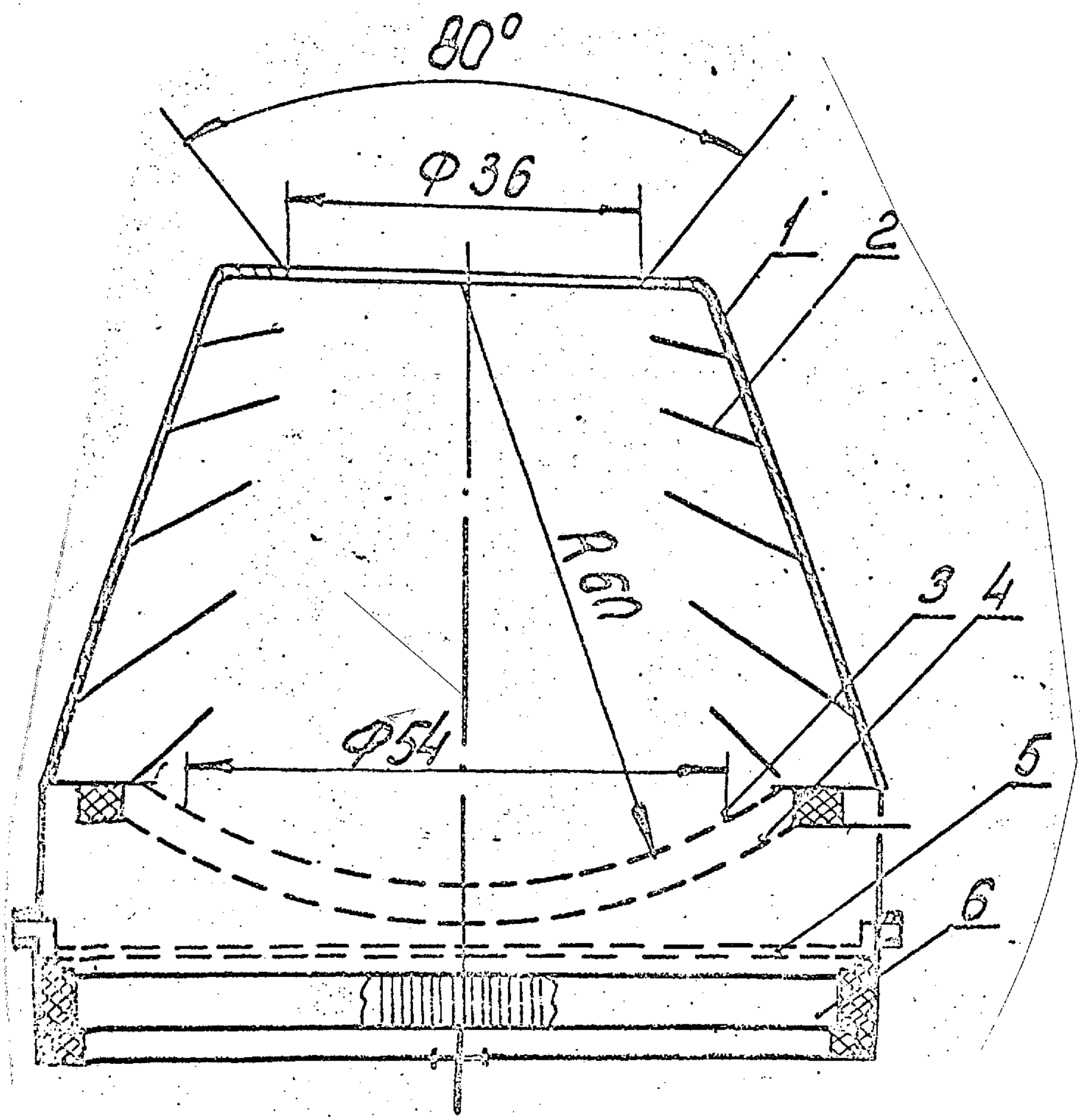


Figure 2. Trap for Measurement of Electron Component

Magnetometer /27

Scientific Leader Candidate of Physical and Mathematical Sciences Sh. Sh. Dolginov

The magnetometer is designed to:

-- answer the question of the actuality of existence of a free magnetic field of Mars;

-- determine the effect of unipolar induction in the ionosphere of Mars;

-- study changes in the shock wave near the planet both in space and in time.

The device is a three-component ferroprobe magnetometer. The sensors of the magnetometer are installed on a bar about 2 meters long. The bar is attached to the solar battery. "Twist" sessions were held to determine the "zero values." The magnetometer operated with a sensitivity of 0.1 $v/\gamma \pm 1.5\%$ over a range of 60 gammas. The calibration signal was supplied on command.

Investigation of the Gamma Radiation of Mars /28

Scientific Leader Doctor of Physical and Mathematical Sciences Yu. A. Surkov

The primary purpose of the experiment with the gamma spectrometer is to determine the spectral composition and intensity of gamma radiation from the atmosphere and surface of the planet, allowing the content of natural radioactive elements and the type of rocks making up the surface of the planet to be determined.

Measurements were performed in the range of gamma radiation energies of 0.6 MeV to 9.0 MeV.

The device consists of two main parts:

a) A scintillation sensor, consisting of an NaI (Tl) sensor surrounded by a scintillation plastic, a photomultiplier and electronic units to amplify the signal and separate the charged particle recording blocking signal;

b) A multichannel pulse amplitude analyzer, which measures the amplitude distribution, records the amplitude spectrum, outputs the spectrum to the telemetry system and controls the experiment.

The analyzer has 256 channels with a capacity of 2^{15}.

Results will be interpreted on the basis of theoretical calculations and model experiments performed in accelerators and balloons.

Temperature and Pressure Meter /29

The sensors of the device for measurement of temperature are four platinum resistance thermometers connected in a bridge measurement circuit. The range of measured temperatures is from -150° to +50° C.

The time constant of the instrument is about 3 sec, the measurement error is ±5%.

Atmospheric pressure is measured by membrane manometers of a special design. There are three sensors, designed to measure the differential, static and total pressure. The measurement ranges are:

0-3 millibar,
0-17 millibar,
0-25 millibar.

The sensing element of each manometer is a plate of an alloy with a negligible coefficient of thermal expansion. The membrane and quartz disc with two electrodes (working and compensating electrodes) spray-coated on form the measuring condensors (capacitances). The condensors are connected in an ac bridge measurement circuit, the signal produced is demodulated and the constant voltage is output to the telemetry system in analog form.

Mass Spectrometer /30

Scientific Leader Doctor V. G. Istomin

The chemical composition of the atmosphere of Mars was determined by means of a radio-frequency mass spectrometer (Bennett type).

The mass spectrometer has the following characteristics:

Range of mass numbers (continuous scanning)		12-48 mμ.
Time required to produce one mass spectrum		4 sec
Resolving capacity at half peak height		20-25
Range of working pressures in area of inlet system		0.5-5.0 torr
Limiting sensitivity to minor components in CO_2 atmosphere:		
Molecular nitrogen	at least	0.5% vol.
Molecular oxygen	at least	0.1% vol.
Argon	at least	0.05% vol.
Dynamic range of output	at least	1.10^4

The mass spectrometer uses a three-stage nine-cycle (2-7 cycle) Bennett radio frequency analyzer, evacuated to a high vacuum (on the order of $1\cdot10^{-9}$ torr) by a magnetic ion pump. The pressure drop between the medium studied, the atmosphere of Mars, and the mass analyzer is maintained by choking the flow through an inlet diaphragm with an aperture of 4-5 microns. The atmosphere of Mars is allowed in through the inlet diaphragm after a glass tube is opened on command. Test (background) spectra are preliminarily recorded.

Special measures are taken in the device to eliminate or minimize the influence of the well-known shortcomings of magnetic ion pumps such as the "memory" effect, back gas diffusion and differences in the rates of pumping of different gasses, on the /31
analytic characteristics. The level of background peaks in the mass spectrum when pure CO_2 (100%) is admitted is:

For the 28 m.u.	not over	4.0%
For the 32 m.u.	not over	0.02%
For the 40 m.u.	not over	0.05%

The error of measurement with a content of the components of at least 5% vol. (considering calibration using model mixtures) is not over ±20% of the content of the corresponding component.

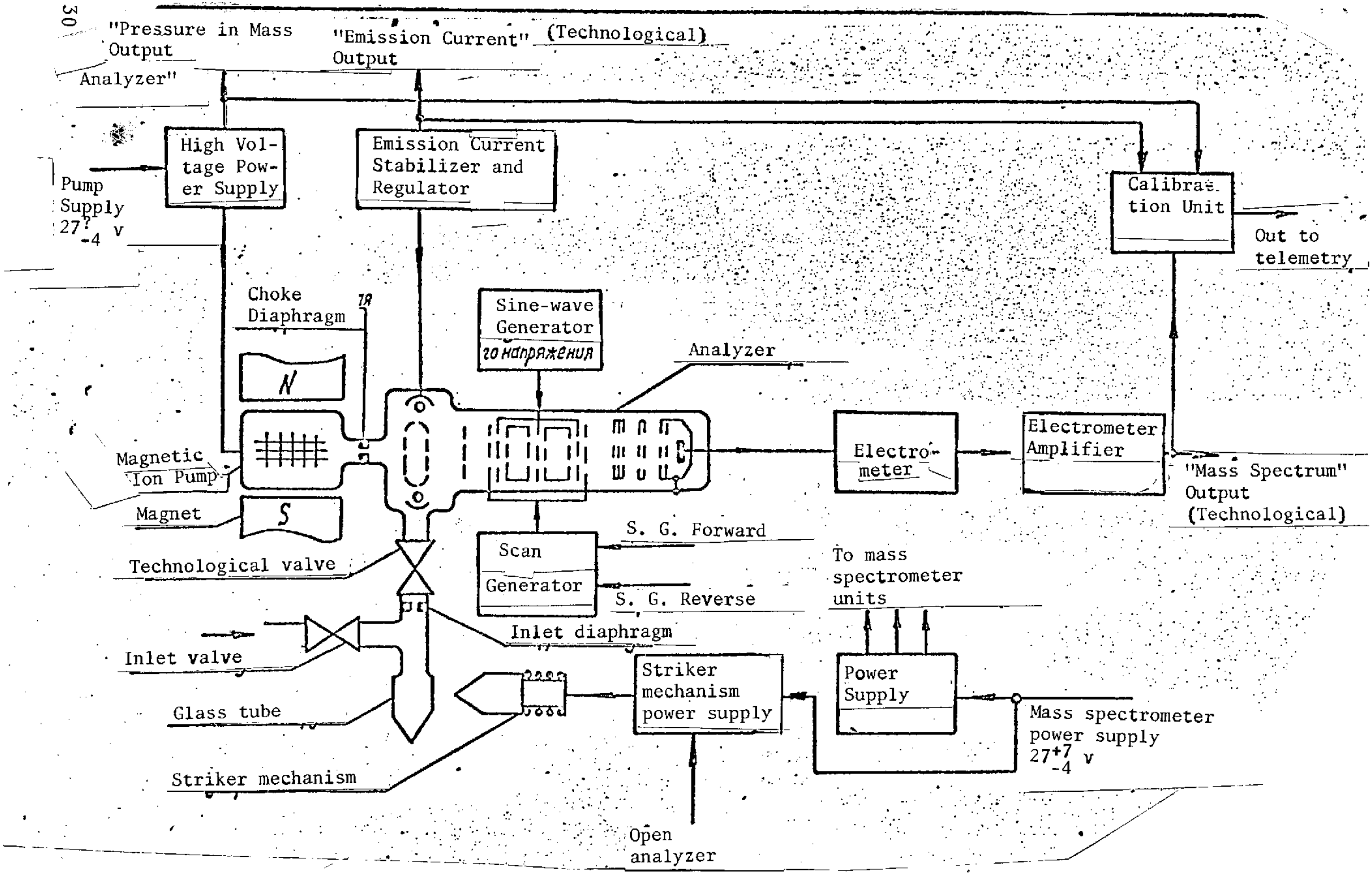


Figure 1. Functional Diagram of the Mass Spectrometer

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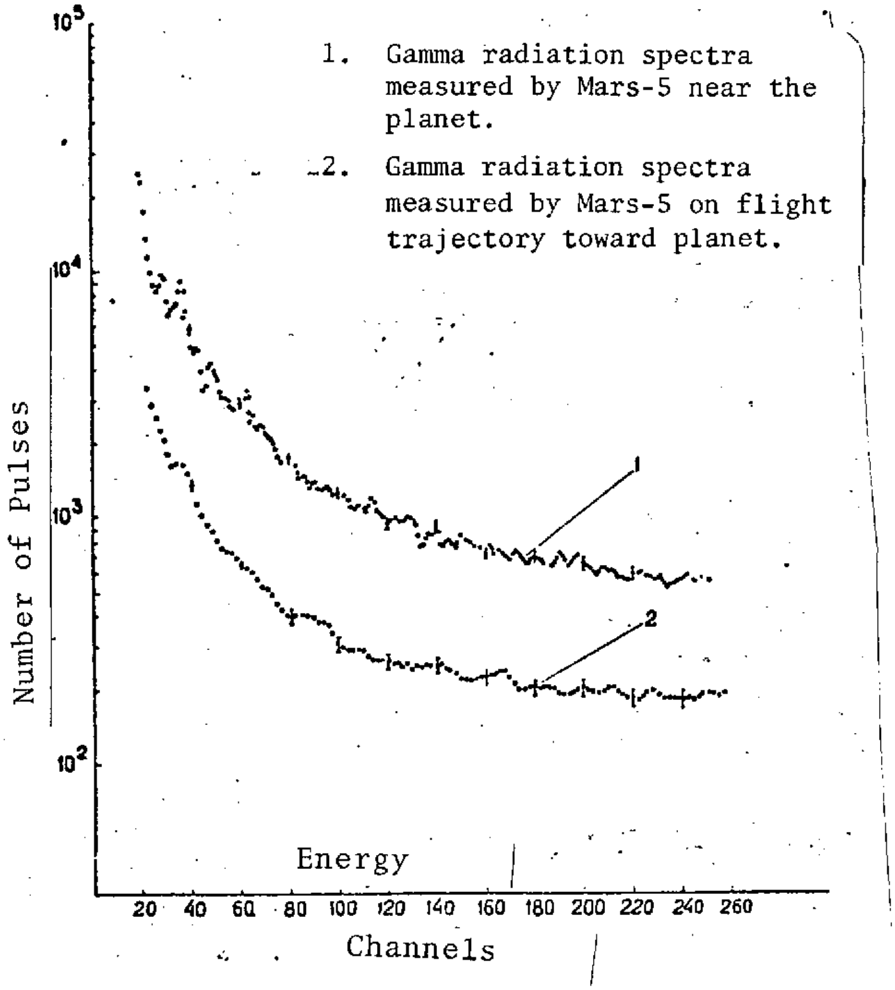
The gamma radiation spectrum was measured from the orbit of the Mars satellite at a distance of about 2000 km. The total level of gamma radiation from Mars was somewhat higher than from the moon. The spectral composition of the gamma radiation of Mars is more complex than that of the moon, since the radiation results from three components: 1) the interaction of cosmic rays with the atmosphere, 2) same with the lithosphere and 3) the decay of natural radioactive elements in the Martian rock. /33

The spectra were measured with good statistics. Peaks are observed in the spectra. Data from model experiments performed in accelerators and balloons as well as theoretical calculations will be used for their identification. The telemetry information is currently being processed.



1. Gamma radiation spectra measured by Mars-5 near the planet.
2. Gamma radiation spectra measured by Mars-5 on flight trajectory toward planet.
Number of Pulses
10^5
10^4
10^3
10^2
Energy
20 40 60 80 100 120 140 160 180 200 220 240 260
Channels
1
2